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Published version:

DOI:10.1071/RJ12108

This paper was published in *The Rangeland Journal*, 2013, 35, 85-93. http://dx.doi.org/10.1071/RJ12108.

1. Use of mineral mix supplements to modify the grazing patterns by cattle for the restoration of sub-alpine and alpine shrub-encroached grasslands

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2.1 Abstract

Throughout the last decades, agricultural abandonment in European mountain areas has caused changes in traditional livestock management with consequences for semi-natural grassland use and vegetation. In the Western Italian Alps, continuous extensive grazing has become the simplest and the most common system for managing large cattle herds. As a result, limited grazing in many rugged locations has led to an extensive shrub-encroachment of semi-natural grasslands in the sub-alpine and alpine belts. A study was conducted to assess if the provision of mineral mix supplements (MMS): 1) increases the use of steep and shrub-encroached locations by beef cows, and 2) helps restore meso-eutrophic grassland vegetation around supplement-deployment sites. During the summer grazing season, MMS were placed within 10 steep and shrub-encroached areas in two adjacent pastures (364 ha and 366 ha), and 12 cows were tracked with GPS collars. For each supplement site, a paired control site was identified, and vegetation surveys were performed in the surrounding areas of both sites. Placement of MMS increased the use of areas within 12 m of supplement locations compared to corresponding control areas. Cattle use of areas within 100 m of the MMS sites was also greater than expected by chance. The use by cattle, associated with trampling, grazing and faecal deposition, reduced the cover of shrubs and oligotrophic herbaceous species and increased the average nutrient *N* value and forage pastoral value of the new vegetation types established around MMS sites two years after their use by cattle. Strategic placement of MMS appears to be a sustainable practice to restore sub-alpine and alpine shrub-encroached grasslands. Nevertheless these results must be considered preliminary as a longer period is needed to evaluate the long-term effectiveness of this practice for the restoration of semi-natural grasslands.

Additional keywords: beef cows, continuous grazing, dwarf shrubs, feed blocks, GPS-tracking, sustainable restoration practice

2.2 Introduction

Over the past decades, agricultural abandonment in European mountain areas has caused changes in the use of semi-natural grasslands, their management, and the composition of their vegetation (MacDonald et al. 2000; Parolo et al. 2011), with extensive shrub and tree encroachment over large areas (Barbaro et al. 2001; Kesting 2009). In the Western Italian Alps, socio-economic changes have affected traditional livestock farming systems during the last 50 years (Pardini and Nori 2011) with the number of livestock farms, permanent grasslands and meadows, and numbers of cattle decreasing by 92 %, 62 %, and 44 %, respectively (ISTAT 2010; Regione Piemonte 2011). These changes have been different across the altitudinal range. Within the montane belt, agricultural land has been broadly abandoned (MacDonald et al. 2000) because of the high fragmentation of private properties and the impossibility to maintain profitable farms with small area. In the montane belt, fast-growing, invasive vegetation has resulted in the development of dense mesophilous forests on former croplands, meadows and pastures (Laiolo et al. 2004; Falcucci et al. 2007). On the contrary, in the higher sub-alpine and alpine belts, a low fragmentation of communal properties has allowed the preservation of a higher number of livestock farms, in a context of markedly modified holding structure and livestock management. Traditional herding, which was associated with a large number of small family farms, has declined (MacDonald et al. 2000) and has been replaced with a small number of farms rearing large herds. In order to reduce labour requirements, continuous extensive grazing has become the simplest and most common system for managing such herds (Güsewell et al. 2005). Higher stocking densities with these larger herds than in the past and the natural predilection of free-ranging cattle for flatter terrain (Bailey 2005) have generally increased grazing in these areas and limited the use of steeper areas (Güsewell et al. 2005). As a consequence, limited grazing of many rugged locations in the sub-alpine and alpine belts has resulted in natural successional phenomena with changes in vegetative cover and composition (Poldini et al. 2004; Elzein et al. 2011). Herbaceous oligotrophic species and dwarf shrubs, predominantly *Rhododendron ferrugineum* L. (alpenrose), *Juniperus nana* Willd. (dwarf juniper), *Vaccinium myrtillus* L. (bilberry) and *Vaccinium gaultherioides* Bigelow (northern bilberry), have encroached large areas of semi-natural grasslands, mainly belonging to the *Nardion strictae*, *Polygono-Trisetion*, and *Poion alpinae* phyto-sociological alliances. Research conducted on 122 summer pastures (average area, 161 ha) in the sub-alpine and alpine belts along the Western Italian Alps (Cavallero et al. 1997) showed that herbaceous oligotrophic species and dwarf shrubs spread over 22 % and 32 % of the area of grassland, respectively. Shrub encroachment has decreased forage yields as well as the nutritive value of the forage (Cavallero et al. 2007; Kesting 2009), increasing homogeneity of the landscape and reducing the habitat for meso-eutrophic herbage characterized by high plant and animal diversity (MacDonald et al. 2000; Laiolo et al. 2004; Hopkins and Holz 2006; Maurer et al. 2006; Falcucci et al. 2007; Patthey et al. 2012).

For these reasons, in many European countries the conservation and restoration of semi-natural grasslands have become an important agri-environmental issue. Such conservation and restoration have been mainly carried out by manual or mechanical shrub-clearing, mowing, prescribed burning and grazing management (Bobbink and Willems 1993; Barbaro et al. 2001; Mitlacher et al. 2002; Pykälä 2003; Ascoli et al. 2009). Livestock can play an important role in the restoration process because trampling, grazing, seed transport and nutrient redistribution through faecal deposition can alter the cover and structure of vegetation as well as botanical composition (Bakker et al. 1996*b*; Olff and Ritchie 1998; Bakker and Berendse 1999; Barbaro et al. 2001; Mitlacher et al. 2002; Pykälä 2003; Ascoli et al. 2013).

Alpine semi-natural grasslands are generally composed of a heterogeneous mosaic of oligotrophic, mesotrophic and eutrophic vegetation types, depending on the differential grazing pressure and soil nutrient availability related to livestock excreta (Güsewell et al. 2005; Cavallero et al. 2007). Higher grazing pressures, along with larger amounts of urine and faeces, favour the development of meso-eutrophic herbaceous vegetation types, characterized by a higher frequency of grazing-tolerant and nutrient-demanding species, with higher forage pastoral value (Güsewell et al. 2005; Cavallero et al. 2007). In addition, cattle can also control the encroachment process by trampling and grazing dwarf shrub species such as *V. myrtillus* (Meisser et al. 2009; Hancock et al. 2010).

Strategic placement of mineral mix supplements (MMS) has been used to entice cattle into traditionally undergrazed areas in different American rangeland systems (Bailey and Welling 2007; Goulart et al. 2008; Aubel et al. 2011). To our knowledge, the strategic placement of MMS has not been evaluated as a tool to restore semi-natural shrub-encroached grasslands. Modification of the grazing patterns of cattle through strategic placement of MMS could be a more sustainable restoration practice than manual or mechanical shrub-clearing or fencing (Barbaro et al. 2001; Meisser et al. 2009), as it is less costly, has lower labour inputs, and could be more easily carried out on rugged alpine locations.

The objective was to assess if MMS could: 1) increase the use of steep and shrub-encroached locations by cattle and 2) help restore meso-eutrophic vegetation around supplement-deployment sites. It was hypothesized that: 1) providing MMS on steep and shrub-encroached locations would result in greater cattle use of areas around placement sites compared to similar control sites, so that 2) cattle trampling, grazing and faecal deposition would reduce the cover of shrubs and oligotrophic herbaceous species and increase the cover of meso-eutrophic herbaceous species.

2.3 Materials and methods

2.3.1 Study area

The study was conducted in Val Troncea Natural Park (Fig.1), located in the Piedmont region of north-west Italy (latitude 44° 57’ N, longitude 6° 57’ E), which is a protected area representative of the changes that have occurred on grasslands in the Western Italian Alps throughout the last decades. Dominant soils were gravelly and nutrient-poor, originating from calcareous parent rock. Annual average air temperature was 0.8 °C (January: -8 °C; July: 9.5°C) and annual average precipitation was 956 mm (long-term mean value, 1951 – 1986; Biancotti et al. 1998). Grasslands were mainly dominated by *Festuca curvula* Gaudin, *Carex sempervirens* Vill., and *Trifolium alpinum* L. The shrub vegetation layer was predominantly composed by *R. ferrugineum*, *J. nana*, *V. myrtillus*, and *V. gaultherioides*, that have rapidly encroached wide areas of grasslands after the decline in agro-pastoral activities. Shrub cover increased from 2 % in 1982 (IPLA 1982) to 18 % in 2011 (unpublished data).

The study area was selected within the two cattle farms still operating in the Park, and consisted of two pastures (Fig. 1): Troncea (366 ha) and Meys (364 ha). Elevations ranged from 1 950 to 3 000 m and slope averaged 29 %. The most extensive grassland and shrubland communities (Cavallero et al. 2007; Argenti and Lombardi 2012) within the entire study area were dominated by *F. curvula* (12 %), *C. sempervirens* (11 %), *Dactylis glomerata* L. (7 %), *T. alpinum* (7 %), *J. nana* (7 %), *Festuca* gr. *rubra* and *Agrostis tenuis* Sibth (5 %), *V. gaultherioides* (5 %), *R. ferrugineum* (5 %), *Festuca quadriflora* Honck. (4 %), and *Salix herbacea* L. (3 %). The Troncea pasture was grazed from 12 July to 29 September 2010 by 119 beef cows, predominantly of the Piedmontese breed, with some of the Valdostana Red Pied and Barà-Pustertaler breeds. The Meys pasture was grazed from 8 July to 20 August and from 7 September to 2 October 2010 by 150 beef cows of the Piedmontese breed. Both groups included heifers and non-lactating cows, varying in age from 1 to 15 years.

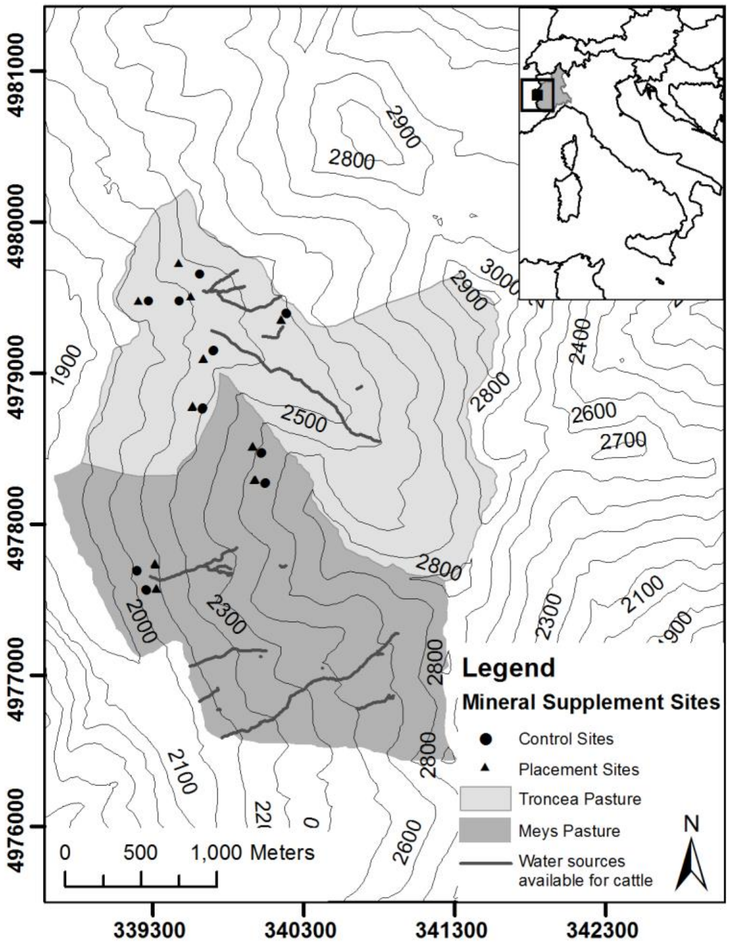

Fig. 1. Location of the study area in Val Troncea, Western Alps (inset), Piedmont, Italy (UTM zone 32 north, WGS84 datum).

2.3.2 Placement of mineral mix supplements and tracking of cattle

During the summer grazing season (early July to early October) of 2010, cows were offered MMS *ad libitum* (Table 1). The MMS were placed at 10 sites, six in the Troncea pasture and four in the Meys pasture (Fig.1). Supplement-deployment sites were positioned within the 10 largest patches of shrub-encroached grassland types and they were on steep areas with an average slope of 48.6 ± 3.4 % (mean ± SE). Within each site, MMS were supplied in 5-kg blocks, which were placed 5 m apart in pairs. Each pair of MMS blocks was considered as a treatment site and was paired with a control site (i.e. without supplements) placed at a maximum distance of 160 m. Control sites had the same soil cover, vegetation features and distances from water sources with respect to MMS sites.

Seven randomly-selected cows per farm were tracked with global position system (GPS) tracking collars (GPS Model Corzo, Microsensory SLL, Fernán Núñez, Andalusia, Spain). Positions were recorded every 15 min, with an average accuracy of 6 m. Locations of MMS were recorded with a hand-held GPS with an accuracy of 1 m. Before the beginning of the study, cattle were given a period of one month to adjust to the GPS collars. Cattle were also used to MMS, as MMS blocks were supplied to the cattle when they were housed during the winter.

Table 1. Composition of mineral mix supplement

Mineral	Concentration (mg/Kg)
Phosphorus	140 000
Sodium	130 000
Calcium	95 000
Magnesium	2 400
Iron	1 400
Copper	500
Manganese	480
Zinc	330
Iodine	120
Cobalt	40
Selenium	10

2.3.3 Surveys of botanical composition and vegetative cover

Botanical composition was determined using the vertical point-quadrat method (Daget and Poissonet 1971; Jonasson 1988) along cross-shaped transects. One transect was placed at each control and supplement site, with the centre of the cross positioned in the exact middle of the pair of MMS blocks. Because of the time required for faecal decomposition, nutrient release and associated vegetation changes at high altitudes (Körner 2003), vegetation was monitored biennially. Twenty vegetative transects were measured in early July 2010, in order to test the homogeneity of vegetation between supplement and control sites before the use of MMS by cattle. Transects were 12.5 m long across each of the four sides of the cross. In each transect, at every 50-cm interval, plant species touching a steel needle were identified and recorded (i.e. 100 points of vegetation measurement). In 2011, MMS blocks were not placed in the study area, and cattle did not intensively graze and further affect vegetation on the steep sites used during the previous year (unpublished data). In early July 2012, the extent of areas, which had been modified by cattle around MMS locations, was visually estimated, following the sharp fine-scale fragmentation of the original dense shrub cover. Fine-scale fragmentation is characterized by the lack of an intact core area and by the lack of difference between the edge and the core of the modified shrub area (Bar Massada et al. 2008). A new cross-shaped transect was placed within each of these changed vegetation areas, with the purpose to evaluate vegetation differences between supplement and control sites. New transects were 5 m long across each side of the cross, in order to better overlap with changed vegetation areas. To maintain the total of 100 points of vegetation measurement, the metal needle was placed at every 20-cm interval, according to the vertical point-quadrat method. In 2010 and 2012, percentage of shrub, herbaceous, and bare ground cover was visually estimated within a 1-m buffer around the transect line.

2.3.4 Data analyses

Use by cattle of areas within 12 m of MMS placement sites (twice the average collar accuracy) was assessed. It is likely that cattle consumed supplement when they were inside the 12-m buffer because placement sites were located on steep slopes that cattle typically avoid. A visit to a MMS site was then defined as the location of a GPS collar within 12 m of the placement site, in accordance with Bailey et al. (2001) who defined a visit to supplement as a collar location within 10 m of placement. The number of visits to each supplement and control site was calculated for each tracked animal. Frequency of visits to supplement sites was calculated as the total number of the visits over the number of days cows were tracked (visits day^{-1}). The number of GPS locations for each collared cow within 100 m of the MMS sites was also computed to quantify the use by cattle of areas near placement sites (Bailey and Welling 2007). The area of the minimum convex polygon was calculated for each cow (Ganskopp 2001). The minimum convex polygon provides a simple general outline of the home range by connecting the outermost GPS locations and it can help distinguish used from unused areas (Zengeya et al. 2011). All geographical analyses were conducted using ArcMap 10 (ESRI 2010).

Distribution of the number of visits per cow to MMS and control sites was tested for normality using the Kolmogorov-Smirnov test (Sokal and Rohlf 1995). Because neither raw data nor log-transformed data were normally distributed, use within 12 m of supplements was compared to corresponding control areas using the non-parametric Wilcoxon signed-rank test (Sokal and Rohlf 1995). Pearson χ^2 test was used to test if the number of locations for each cow within 100 m of the MMS sites differed from expected frequencies based on the average cattle use in the minimum convex polygon area (Lehner 1998).

For each plant species recorded in the vegetative transects the frequency of occurrence (f_i = number of occurrences/100 points), which is an estimate of species canopy cover (Gallet and Roze 2001) was calculated. Species Relative Abundance (SRA_i) was calculated and used to detect the proportion of different species, according to the equation of Daget and Poissonet (1971):

$$\mathrm{SRA}_i = \frac{f_i}{\sum_{i=1}^{i=n} f_i} \times 100\ (\%)$$

The demand of each plant species for nutrients was estimated according to the Landolt nutrient value (index N, Landolt 1977) and each plant species was classified as oligotrophic (N = 1, 2), mesotrophic (N = 3), and eutrophic (N = 4, 5). Within the oligotrophic species category, shrub and herbaceous species were distinguished whereas within the mesotrophic and eutrophic categories all species were herbaceous. The two most frequent species within each of the three herbaceous categories (oligotrophic, mesotrophic, and eutrophic) were identified. Frequency and relative abundance were calculated for *R. ferrugineum*, *J. nana*, and *V. myrtillus* + *V. gaultherioides* (separately and together), as well as for oligotrophic, mesotrophic, and eutrophic herbaceous species (for all the species pooled together within each category and separately for the two most frequent species).

An indirect vegetation index was calculated to evaluate the overall effect of fertilization produced by the cattle, as the exact amount of dung and urine excreted in the surrounding areas of MMS was extremely difficult to assess. An average vegetation N index ($N_{average}$), weighted for species relative abundance, was computed for each transect according to the equation:

$$N_{\mathrm{average}} = \frac{\sum_{i=1}^{i=n} (\mathrm{SRA}_i \times N_i)}{100}$$

where N_i is the N nutrient value for the species i.

Each species was also classified according to the Index of Specific Quality (ISQ) (Daget and Poissonet 1971; Cavallero et al. 2007). The ISQ is based on preference, morphology, structure, and productivity of the plant species found in the Western Italian Alps, and it ranges from 0 (low) to 5 (high). In each transect, forage pastoral value (PV), a synthetic value summarizing forage yield and nutritive value ranging from 0 to 100 was calculated (Daget and Poissonet 1971). Forage pastoral value is weighted for species relative abundance and is calculated using the following equation:

$$\mathrm{PV} = \sum_{i=1}^{i=n} (\mathrm{SRA}_i \times \mathrm{ISQ}_i) \times 0.2$$

where ISQ_i is the ISQ value for the species i.

Kolmogorov-Smirnov test for normality and Levene test for homogeneity of variance were used to evaluate the distribution of vegetation variables. Variables not normally distributed were subjected to a log(x + 1)-transformation that normalized the data. A Pearson correlation (Sokal and Rohlf 1995) was used to estimate the association between overall number of visits to supplement sites (all tracked cows pooled together) and the following variables measured in the changed vegetation areas: extent of the area, shrub cover, average vegetation N index, and forage pastoral value. Soil cover and vegetation variables between supplement and their control sites were compared using paired-samples *t* tests (Sokal and Rohlf 1995). All the statistical analyses were performed using IBM SPSS Statistics 19 (SPSS 2010).

2.4 Results

2.4.1 Use of sites with mineral mix supplements by cattle and effects produced on soil cover

One collar per farm failed, so tracking data were obtained from 6 collared cows for each pasture. During the study, 92 % (11 out of 12) of collared cows visited MMS, and 90 % of MMS sites (nine out of 10) were visited by collared cows. Visits per cow to MMS sites (4.09 ± 0.913 visits) were greater ($P < 0.01$) than those to paired control areas (1.13 ± 0.332). Sites with MMS were visited approximately once every six days (0.16 ± 0.031 visits day^{-1}). Minimum convex polygon areas were 320.5 ± 7.61 ha. Number of GPS locations within 100 m of the MMS sites (288 ± 54.0) was greater ($P < 0.001$) than the expected number of locations based on average cattle use of the minimum convex polygon area (205 ± 24.8). The overall number of cattle visits to supplement sites (ranging from zero to 53 visits) was strongly related to the extent of changed vegetation areas measured in 2012 (Fig.2a), which ranged from 0.0 to 98.9 m^2 (45.2 ± 9.51 m^2).

No statistical differences in variables of visually estimated cover were detected between MMS and control sites in 2010. Two variables of cover around supplement-deployment sites differed from corresponding control sites in 2012 (Table 2). Shrub cover was lower ($P < 0.001$) at the MMS sites than at the control sites. No differences in herbaceous cover were detected between the MMS and control sites but the percentage of bare ground was higher around MMS sites ($P < 0.001$).

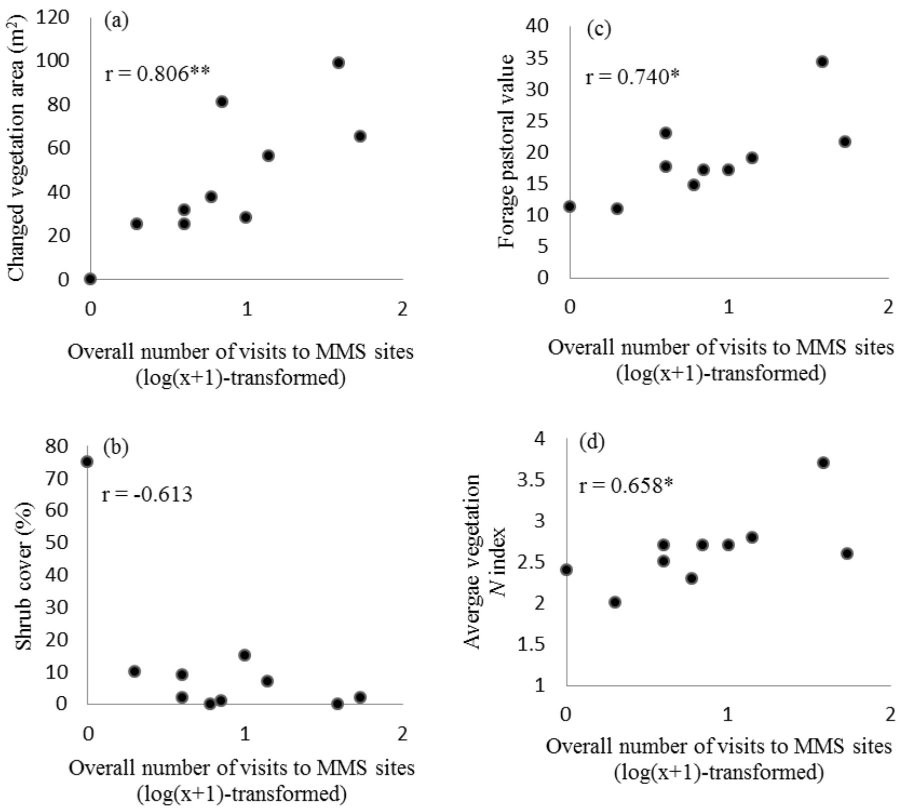

Fig. 2. Relationship between the number of visits to MMS sites (transformed by log(x+1)) of all collared cows and a) the extent of impacts of cattle on vegetation near MMS, b) shrub cover, c) forage pastoral value, and d) average vegetation *N* index of the vegetation within 5 m of MMS placements. Pearson correlation coefficients are given for each graph (*, $P < 0.05$; **, $P < 0.01$).

Table 2. Mean cover values of paired control sites (n = 10) and sites of mineral mix supplement (MMS) placement (n = 10), two years after supplement use by cattle in the Western Italian Alps

	Control sites	MMS sites	s.e. of mean	t-statistic	Level of significance
Shrub Cover (%)	55.60	12.10	5.85	4.81	*P* < 0.001
Herbaceous Cover (%)	35.40	39.40	5.93	-0.61	*P* = 0.555
Bare Ground (%)[1]	9.00	48.50	1.57	-5.55	*P* < 0.001

2.4.2 Effects produced on botanical composition

No differences in vegetation variables were detected between the MMS and control sites in 2010. It was assumed, therefore, that supplements and control sites had roughly the same vegetation and ecological features before cattle used the MMS.

Within all vegetative transects in 2010 and 2012, a total of 151 plant species was detected (149 perennial species accounting for 99 % of the relative abundance). The most frequent herbaceous species were: *F. curvula* and *Poa chaixii* Vill. (oligotrophic), *Anthoxanthum alpinum* A. and D. Löve and *Festuca violacea* Gaudin (mesotrophic), *Poa alpina* L. and *Phleum alpinum* L. (eutrophic).

In 2012, a reduction ($P < 0.001$) in cover (frequency) and relative abundance of shrub species was detected near MMS placement sites (Table 3). Oligotrophic herbaceous species cover declined ($P = 0.05$) at MMS sites, whereas no differences in relative abundance were detected between supplement and control sites. Analyses performed on the most frequent oligotrophic herbaceous species cover highlighted different species-specific trends: *P. chaixii* increased within MMS sites ($P < 0.05$), whereas no differences in *F. curvula* were detected. No changes in mesotrophic species were detected around MMS locations, neither for the two most frequent species nor for all the species considered together. Percentage of eutrophic species on the total of species was higher ($P < 0.01$) around supplement-deployment sites, although their cover did not increase significantly. An increase in average vegetation N index ($P < 0.01$) and forage pastoral value ($P < 0.01$) was detected around supplement-deployment sites. These two vegetation variables were also related ($P < 0.05$) with the overall number of cattle visits to MMS sites (Fig.2c and Fig.2d).

Table 3. Mean species composition, average vegetation *N* index, and forage pastoral value of paired control sites (n = 10) and sites of mineral mix supplement (n = 10), two years after supplement use by cattle in the Western Italian Alps. n.s., Not significant at P < 0.05

		n[1]	Control sites	MMS sites	s. e. of mean	t-statistic	Level of significance
Species frequencies (cover)	Shrub species	10	66.90	12.80	8.16	4.60	$P < 0.001$
	Rhododendron ferrugineum[2]	5	28.60	1.80	1.11	3.42	$P < 0.05$
	Juniperus nana	6	38.50	1.20	0.60	5.37	$P < 0.01$
	Vaccinium myrtillus + *Vaccinium gaultherioides*	8	29.50	11.20	8.50	2.28	$P < 0.05$
	Oligotrophic herbaceous species	10	80.20	47.20	14.71	2.24	$P < 0.05$
	Festuca curvula	5	9.60	10.20	4.21	-0.02	n.s.
	Poa chaixii	9	6.33	10.67	1.71	-2.13	$P < 0.05$
	Mesotrophic species	10	13.10	16.20	2.51	-0.52	n.s.
	Anthoxanthum alpinum	7	2.86	4.14	1.23	-1.34	n.s.
	Festuca violacea	6	5.83	4.33	1.36	0.86	n.s.
	Eutrophic species	10	13.00	15.30	3.40	-0.56	n.s.
	Poa alpina	7	11.86	9.57	2.28	0.63	n.s.
	Phleum alpinum	7	3.14	7.29	1.82	-1.31	n.s.
Species relative abundances (%)	Shrub species	10	38.30	10.31	3.72	4.99	$P < 0.001$
	Rhododendron ferrugineum	5	13.94	1.84	1.23	2.47	n.s.
	Juniperus nana[2]	6	22.48	1.78	1.15	10.25	$P < 0.001$
	Vaccinium myrtillus + *Vaccinium gaultherioides*	8	17.82	8.32	5.04	2.76	$P < 0.05$
	Oligotrophic herbaceous species	10	46.13	50.03	5.92	-0.66	n.s.
	Festuca curvula[2]	5	6.50	13.61	6.10	-0.45	n.s.
	Poa chaixii[2]	9	4.12	13.33	5.83	-2.26	n.s.
	Mesotrophic species	10	7.62	14.34	1.48	-1.42	n.s.
	Anthoxanthum alpinum[2]	7	1.51	4.07	2.10	-0.27	n.s.
	Festuca violacea	6	3.78	3.82	1.71	-0.01	n.s.
	Eutrophic species[2]	10	7.95	25.32	2.12	-3.23	$P < 0.01$
	Poa alpina[2]	7	7.78	20.46	11.13	-1.59	n.s.
	Phleum alpinum[2]	7	1.81	7.97	2.69	-2.11	n.s.
	Average vegetation *N* index	10	2.20	2.64	0.05	-4.01	$P < 0.01$
	Forage pastoral value	10	8.91	18.71	1.42	-4.42	$P < 0.01$

[1] *n* is the number of couples of MMS-control sites in which the species were present (from 5 to 10).

[2] Paired *t*-test performed on log(x+1)-transformed data.

2.5 Discussion

2.5.1 Use of sites with mineral mix supplements by cattle and effects produced on soil cover

Bailey and Welling (2007) reported than only 56 % of collared cows visited mineral mix supplements, which is much lower than the 92% observed in this study. This difference may be a consequence of a longer period of tracking in this study (70 days for the Meys pasture and 80 days for the Troncea pasture) as Bailey and Welling (2007) tracked cows for 1-week periods. Cattle regularly travelled to the MMS and the data support the hypothesis that strategic placement of MMS on steep and shrub-encroached locations can increase cattle use up to 100 m from placement sites. Considering that supplement placement areas were historically underused and located in extremely steep and rugged terrain, these results are promising and suggest that cattle can be successfully used on similar landscapes and vegetation mixes. Within a few metres around supplement-deployment locations, concentrated trampling and grazing can produce an intense effect to reduce shrub cover, which can be useful for the restoration of shrub-encroached grasslands. Moreover, within a wider area around supplement-deployment locations, modification of grazing patterns, and related deposition of faeces and urine, can also produce a less intense effect useful for the exploitation and conservation of meso-eutrophic vegetation.

In contrast, research conducted in Brazil (Goulart et al. 2008) and in the United States (Bailey and Welling 2007; Aubel et al. 2011) found that mineral mix supplements were not effective attractants and did not help increase cattle use of traditionally undergrazed areas. Comparisons of these studies with this study are difficult, because the composition of the mineral mix supplements, environmental conditions and experimental designs differed among the studies.

Cattle impacts on cover around placement sites were localized and never exceeded 100 m^2. Near sites of MMS placement, cattle trampling and grazing reduced shrub cover. Two years after MMS placement, bare ground gaps created by cattle were mostly not covered by herbaceous vegetation. In fact, bare ground occupied almost half of these areas, showing that recolonization by herbaceous vegetation is a slow process. The slow recolonization pattern could be attributed to several factors at high altitudes. The seed bank of many grassland species under dense shrub canopy is transient (Bakker et al. 1996*b*; Bakker and Berendse 1999; Barbaro et al. 2001), and the large distance from MMS sites to seed banks of grassland species in the study area may not allow seeds to spread successfully. The range of seed dispersal for most of grassland species is only a few metres (Barbaro et al. 2001; Dzwonko and Loster 2007). In addition, cattle trampling around MMS could have resulted in soil compaction (Greenwood and McKenzie 2001) and decreased seedling establishment. Another limiting factor could have been the low temperatures at these high altitudes limiting biochemical processes, the growing season and vegetation cycles (Körner 2003; Makarov et al. 2003).

2.5.2 Effects produced on botanical composition

Although the study was limited to two years, MMS placement and subsequent targeted grazing appear to have potential for restoring shrub encroached grasslands. Both overall shrub cover and relative abundance clearly decreased near MMS placement sites. It may only take a minimal number of visits by cattle to reduce shrub cover (Fig.2b). The presence of cattle apparently causes serious mechanical damage, probably through trampling, to the branches of shrubs, particularly *J. nana* and *R. ferrugineum*, which did not show any sign of re-sprouting, confirming what Barbaro et al. (2001) observed in a similar environment.

The forage pastoral value approximately doubled near MMS sites. The strong correlation between cattle visits to MMS and forage pastoral value provides additional evidence that targetted grazing by cattle may be useful for restoring shrub-encroached grasslands in this region. Unfortunately, areas near MMS sites had a high percentage of bare ground and small size of new seedlings which would not be particularly attractive to cattle. It is likely, however, that perennial grasses and forbs will increase in a few years and the corresponding improvement in forage pastoral value could entice cattle to graze steep locations. This positive reinforcement might result in a phenomenon termed as ‘herbivore-mediated positive feedback’ (Wilson and Agnew 1992).

The vegetation *N* index increased near MMS placements and was correlated with cattle visits to the MMS. This may be a result of the deposition of faeces and urine which can increase nutrient availability in the soil (Güsewell et al. 2005). Nonetheless, the vegetation data do not allow validation of all the restoration hypotheses made about changes in herbaceous species. Cover of oligotrophic species decreased but that of mesotrophic and eutrophic species did not increase on the areas of bare ground. The only species that showed a significant increase in canopy cover was *P. chaixii* that, although oligotrophic according to Landolt (1977), has been classified as pre-forest mesotrophic species by Cavallero et al. (2007), and appears to benefit at an early stage from the reintroduction of grazing after abandonment (Krahulec et al. 2001). Vegetation changes observed in this study were short-term. Long-term studies are needed (Bakker et al. 1996*a*) to determine if strategic placement of MMS can result in sustained reductions in shrub cover and subsequent establishment of desired herbaceous vegetation in these steep and high altitude alpine grasslands.

It is suggested that supplements should be strategically placed at the edge of shrub-encroached vegetation patches because the cattle impact to vegetation near MMS placements is localized. If MMS is placed at the edge of shrub-encroached areas, they could be more visible and accessible to cattle, and seed dispersal from adjacent seed banks of grassland species might be more successful. In order to expand the restoration effect on a wider area and achieve more effective results, MMS placement should be changed every year, progressively moving from the edge to the centre of shrub-encroached vegetation patches.

2.6 Conclusions

In sub-alpine and alpine grasslands, strategic placement of MMS on steep and shrub-encroached locations was shown to increase the use by cattle of areas historically avoided, that correspondingly provides a small increase in the carrying capacity of the pasture. Cattle trampling, grazing, and faecal deposition may help restore vegetation structure and composition around supplement sites, reducing shrub and oligotrophic herbaceous species cover, and increasing average nutrient value *N* index and forage pastoral value of the new vegetation types. However, establishment of herbaceous vegetation in bare ground gaps created by animal disturbance may require well over the two years of observation in this study. For this reason, results from this study must be considered as preliminary, as a longer period is needed for evaluating the long-term effectiveness of restoration.

Strategic placement of MMS may be a viable management option to be considered for restoration of sub-alpine and alpine shrub-encroached grasslands within agri-environmental schemes. Strategic placement of MMS is more sustainable than manual and mechanical shrub-clearing and fencing, as it is less costly, requires less labour, and it is more practical for rugged alpine terrain. Nevertheless, due to the localized restoration effect produced, never exceeding 100 m^2, strategic placement of MMS should be combined with other livestock management measures, such as the use of night camps or pens on shrub-encroached vegetation (Zhang et al. 2001). Consequently, additional research on the use of targetted cattle grazing to restore shrub-encroached sub-alpine and alpine grasslands and associated economic evaluations appear warranted.

2.7 Acknowledgements

The authors thank particularly Prof. Andrea Cavallero, the research project leader, the Giletta and Raso farmers for their great collaboration, the Val Troncea Natural Park for its helpfulness, and the Faculty of Veterinary Medicine of the University of Calgary for its support. Special thanks are extended to Davide Cugno, Marco Grella, Gabriele Iussig, Marco Pittarello and Guido Teppa for help with the completion of the project. The first author, Massimiliano Probo, was funded by an annual scholarship from Fondazione CRT and Fondazione Goria.

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